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Low Velocity Performance of a High Speed Vane Anemometer

L. P. Purtell

National Bureau of Standards
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Task Report

on
Contract No. H0166198
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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

Dr. Sidney Harman, *Under Secretary*

Jordan J. Baruch, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Performance of a high speed vane anemometer is evaluated over the speed range of 43.4 to 741 feet per minute including starting speed and stopping speed. The tests were performed in the NBS Low Velocity Airflow Facility which provides a uniform flow of low turbulence and utilizes a laser velocimeter as the velocity standard.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Airflow; anemometer; laser velocimeter; low velocity; performance; vane anemometer; wind tunnel.

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- FOREWORD -

This report was prepared by the National Bureau of Standards, Fluid Engineering Division, Washington, D. C. 20234, under USBM Contract Number H0166198. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of PM&SRC, with Dr. George H. Schnakenberg, Jr., acting as the Technical Project Officer. Mr. H. R. Eveland was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period June 1, 1977 to July 31, 1977. This report was submitted by the author September 1978.

LIST OF SYMBOLS

U	velocity measured by laser velocimeter
U_i	velocity indicated by anemometer under test
U_{if}	line segments fitted to U, U_i data
$\overline{U}$	group mean true velocity
$\overline{U}_i$	group mean indicated velocity
σ_i	standard deviation of U_i data from U_{if}
σ	standard deviation of U_i data expressed as true velocity .
σ_c	σ adjusted for known variance in laser velocimeter measurements

LOW VELOCITY PERFORMANCE OF A HIGH SPEED VANE ANEMOMETER

L. P. Purtell

1. INTRODUCTION

The National Bureau of Standards in order to meet the need for a calibration capability with adequate accuracy at low air velocities, i.e., below 500 feet per minute (fpm) undertook the development of a low-velocity calibration facility for wind speed measuring instruments which would provide a capability down to 3 meters per minute (approximately 10 fpm) with an accuracy of plus or minus one percent. It was a natural consequence therefore that when said facility became operational to undertake an evaluation of the state-of-the-art and to provide the information needed as to the reliability and performance of instrumentation for such measurement. Accordingly, a number of prototypes of various types of instruments for low velocity air measurements are undergoing test at NBS, and this report is concerned specifically with the results of one such test.

2. THE INSTRUMENT

The rotary vane anemometer tested for this report is a commercially available instrument (Davis Instrument Manufacturing Co., Inc., 4-Inch High Speed Anemometer, S/N 31125 B)[1] used in the mining industry and elsewhere as a portable anemometer. It was supplied for test by the U. S. Mining Enforcement and Safety Administration (MESA) at the request of the U. S. Bureau of Mines. The housing is 4 inches in diameter and 1-3/4 inches deep (Figure 1). Thin metal vanes without camber or twist mounted on arms drive a rotor linked to a dial indicator by a gear train. The bearings in this particular instrument are ball bearings (as opposed to standard bronze sleeve bearings). This anemometer differs from that reported on previously [1] in that it has only four vanes instead of eight. One revolution on the dial represents an indicated passage of 100 feet of air through the instrument. Thus an external timer (not a part of the anemometer) is required to complete a measurement of velocity (an <u>average</u> velocity for the duration of the measurement).

[1]This particular instrument was selected as being representative of this type of anemometer and its selection does not represent an endorsement.

3. THE TESTS

The NBS Low Velocity Airflow Facility [2] used to test this instrument generates a low velocity air stream having a low turbulence intensity (less than 0.05%) and a large region of uniform flow (at least 75 x 75 cm). A laser velocimeter is employed as a primary velocity standard. It is nonintrusive, has a linear response with velocity, and has good spatial resolution. Adequate sensitivity is obtained without the artificial seeding of scattering particles. Thus the difficulties and inconvenience associated with seeding and the possible effect of such seeding on the performance of the device under test are avoided.

The vane anemometer was mounted on the centerline of the tunnel test section one meter downstream of the entrance to the test section in a manner to minimize the effect of the support on the air stream around the anemometer (Figure 1). Since the anemometer itself modifies the airflow in the tunnel, the velocity should be measured at a location in the flow which has the same velocity in the presence of the anemometer as it does in the absence of the anemometer. Since this anemometer is identical in shape to a bronze bearing anemometer tested previously, the results are used from the tests on that instrument wherein the velocity upstream of the anemometer on the centerline was measured to find the position where deceleration of the flow due to the presence of the anemometer was no longer detectable within the scatter of the measurements. These measurements were performed at two free-stream speeds, 700 and 72 fpm, and as predicted by ideal flow theory the variation of the ratio of the local velocity to the free-stream velocity with distance upstream of the anemometer is independent of free-stream velocity (Figure 2). A distance of 30 cm upstream of the anemometer was chosen as the position for velocity measurement by the laser velocimeter. With no anemometer in the tunnel, variation in velocity along the centerline is imperceptible over the distance traversed (30 cm).

The air speed indicated by the vane anemometer was computed from initial and final readings of the dial and of the associated time interval (around two minutes). The anemometer runs continuously in the tunnel since it cannot be accessed while the tunnel is in operation without disturbing the flow. Thus the readings of the anemometer were performed with the anemometer in operation. The laser velocimeter measurement of the air velocity was performed during the time interval for reading the vane anemometer. Five separate test runs were made, each consisting of ten such measurements over the range 43.4 to 741 fpm. The lower velocity was limited by the starting and stopping speeds of the instrument. The data are presented in chronological order in Tables 1A to 1E.

To determine the starting speeds of the instrument, the velocity in the tunnel was increased from below the starting speed at a smooth acceleration of approximately 30 fpm/min until movement of the vanes could be detected by eye. At that moment the air velocity would be fixed and the laser velocimeter measurements initiated. If the anemometer continued rotating for at least thirty seconds and did not decelerate, the measurement of velocity by the laser velocimeter was recorded as the starting speed. Ten such measurements are presented in Table 2 and have an average of 47.8 fpm and a standard deviation of 2.4 fpm.

Because of the anemometer's angular momentum, stopping speed is more difficult to determine than starting speed. Some preliminary runs indicated that a two minute interval between reductions in air velocity of approximately 2 fpm was sufficient for the anemometer to come to rest if the stopping speed has been reached. Ten such measurements are presented in Table 3 with an average of 31.7 fpm and a standard deviation of 1.7 fpm.

4. TEST RESULTS

Since a particular air speed in the wind tunnel cannot be exactly reset from run to run, scatter in the test data is distributed along a curve, thus prohibiting computing the standard deviation of the data from a simple average. Instead, deviations from a curve fit to the data were computed and the standard deviation approximated by the r.m.s. value of these deviations within a group. The groups are

$$U < 50 \text{ fpm}$$

$$50 \text{ fpm} < U < 60 \text{ fpm}$$

$$60 \text{ fpm} < U < 80 \text{ fpm}$$

$$80 \text{ fpm} < U < 100 \text{ fpm}$$

$$100 \text{ fpm} < U < 150 \text{ fpm}$$

$$150 \text{ fpm} < U < 250 \text{ fpm}$$

$$250 \text{ fpm} < U < 400 \text{ fpm}$$

$$400 \text{ fpm} < U < 500 \text{ fpm}$$

$$500 \text{ fpm} < U < 700 \text{ fpm}$$

$$700 \text{ fpm} < U$$

Since a curve fit to the data would have very little curvature and since the groups of data are compact (small range of U within a group; see Fig. 3), a straight line segment is used to approximate the curve within a group. The line segment passes through the point $(\overline{U},\overline{U}_i)$, the group mean true velocity and the group mean indicated velocity.[1] The slope of the line segment is computed as the average of the slopes of two lines, both passing through $(\overline{U},\overline{U}_i)$ of the group being considered, one line passing through the $(\overline{U},\overline{U}_i)$ of the adjacent group higher in velocity, and one line passing through $(\overline{U},\overline{U}_i)$ of the adjacent group lower in velocity. For the highest group ($U > 700$ fpm) there is only one adjacent group, and thus the line segment for this highest group passes through $(\overline{U},\overline{U}_i)$ of that adjacent group. The line segment for the lowest group ($U < 50$ fpm) is similarly formed.

Designating the above line segments as U_{if}, the standard deviation, σ_i of the indicated velocity, U_i, about the fitted segments is determined by squaring the differences between the U_i data and U_{if}, i.e., $[U_i(U) - U_{if}(U)]^2$. Since the data within the specified groups are reasonably compact, the mean of the squared differences within a group is taken as an estimate of the variance of U_i about U_{if} within that group and specified at that group's mean true velocity, $\overline{U}$. To convert this to a standard deviation in terms of true velocity, designated σ, each $\sigma_i(\overline{U})$ is divided by the slope (dU_{if}/dU) of the line segment associated with the $\sigma_i(\overline{U})$. Note that this σ does not include the "scatter" in the U measurements (due to the inability to exactly reset the wind tunnel to a specified speed), but does include the uncertainty in a particular laser velocimeter measurement. This uncertainty may be estimated from repeated measurements of velocity at a particular fan setting, thus also including any unsteadiness in the velocity, and is estimated as 0.001U for this report. A standard deviation, σ_c, corrected for the laser velocimeter uncertainty may then be computed from

$$\sigma_c^2 = \sigma^2 - (0.001U)^2$$

for any given U. σ and σ_c are presented in Figure 4 as velocity and Figure 5 as percentage of $\overline{U}$. Since $\pm 2\sigma_c$ is extremely close to the 95 percent confidence interval for one measurement, curves of $\pm 2\sigma_c$ are also included in Figure 3 as dashed lines.

The actual differences between the true and indicated velocities, $U - U_i$, are presented in Figure 6 and as a percentage of U in Figure 7. The curves shown in each figure have been drawn for reference only.

5. DISCUSSION OF RESULTS

The instrument performed over the speed range tested with no erratic behavior. The repeatability of the starting and stopping speeds was quite good having standard deviations of 2.4 fpm (5.0%) and 1.7 fpm (5.4%), respectively. Some general comments concerning application of the instrument follow. With any measurement problem the instrument's capabilities should be matched to the required measurement.

This anemometer is intrusive, i.e., it must be placed in the flow.

This anemometer is entirely mechanical and does not require an outside source of power.

Many other factors that can affect the suitability of an instrument for a particular application, such as turbulence or unsteadiness of the air stream, rough handling (shock and vibration), dirt and other environmental factors, time, orientation to the velocity and gravity vectors, etc., have not been tested herein but should be considered.

6. SUMMARY

The performance of a 4-inch diameter high speed vane anemometer with ball bearings has been evaluated, including starting speed and stopping speed, at air speeds up to 741 fpm.

The starting and stopping speed measurements are presented and give an average starting speed of 47.8 fpm and an average stopping speed of 31.7 fpm.

7. REFERENCES

1. L. P. Purtell, Low Velocity Performance of a Ball Bearing Anemometer, NBSIR 78-1485, 1978.

2. L. P. Purtell and P. S. Klebanoff, The NBS Low Velocity Airflow Facility in preparation.

Table 1A
Davis Vane Anemometer
Serial No. 31125B

Indicated Air Speed, fpm	True Air Speed, fpm
785	736
639	606
496	478
359	347
219	217
136.4	141.2
80.2	92.1
53.7	68.2
38.9	56.6
28.6	47.7

T = 23.6 ^{o}C
B = 753.8 mm Hg

Table 1B
Davis Vane Anemometer
Serial No. 31125B

Indicated Air Speed, fpm	True Air Speed, fpm
786	741
640	608
497	477
358	348
219	218
137.3	141.7
81.8	93.1
56.1	70.2
41.8	58.8
26.4	47.3

T = 23.8 ^{o}C
B = 753.8 mm Hg

Table 1C
Davis Vane Anemometer
Serial No. 31125B

Indicated Air speed, fpm	True Air Speed, fpm
786	738
641	608
498	477
358	347
218	216
135.5	139.5
81.1	91.5
53.7	68.0
38.9	55.7
24.5	43.4

T = 24.2 ^{o}C
B = 753.8 mm Hg

Table 1D
Davis Vane Anemometer
Serial No. 31125B

Indicated Air Speed, fpm	True Air Speed, fpm
787	738
641	608
498	477
359	347
220	217
135.6	140.5
80.6	91.4
53.0	67.7
37.8	55.4
24.8	44.6

T = 24.6 ^{o}C
B = 753.8 mm Hg

Table 1E
Davis Vane Anemometer
Serial No. 31125B

Indicated Air Speed, fpm	True Air Speed, fpm
786	740
641	608
498	476
357	347
219	217
134.6	140.0
81.0	91.4
52.6	67.1
38.3	55.3
27.1	46.3

T = 24.7 ^{o}C
B = 753.2 mm Hg

Table 2
Davis Vane Anemometer
Serial No. 31125B

Starting Speed, fpm
51.4
48.2
47.8
46.8
50.2
46.6
50.0
45.2
48.3
43.6

Average Starting Speed, 47.8 fpm

Standard Deviation, 2.4 fpm

Table 3
Davis Vane Anemometer
Serial No. 31125B

Stopping Speed, fpm
33.5
31.4
34.0
29.9
33.0
30.9
33.6
30.9
30.5
29.3

Average Stopping Speed, 31.7 fpm
Standard Deviation, 1.7 fpm

Table 4A
Davis Vane Anemometer
Serial No. 31125B

Indicated Air Speed, fpm	True Air Speed, fpm
782	722
1052	974
3260	3000
5460	4960
7700	6960
9840	9000

$T = 25.8$ to $26.0\ ^{o}C$
$B = 745.6$ to 753.8 mm Hg

Table 4B
Davis Vane Anemometer
Serial No. 31125B

Indicated Air Speed, fpm	True Air Speed, fpm
783	735
1057	988
3260	3000
5450	4950
7690	6960
9620	8970

T = 26.1 to 26.4 ^{o}C
B = 745.0 to 753.8 mm Hg

Table 4C
Davis Vane Anemometer
Serial No. 31125B

Indicated Air Speed, fpm	True Air Speed, fpm
781	730
1058	978
3260	3000
5450	4960
7740	6960
9830	8980

T = 26.4 to 26.5 ^{o}C
B = 745.0 to 753.3 mm Hg

Table 4D
Davis Vane Anemometer
Serial No. 31125B

Indicated Air Speed, fpm	True Air Speed, fpm
780	736
1053	988
3260	3000
5450	4940
7590	6950
10,150	8960

T = 26.6 to 26.8 ^{o}C
B = 744.7 to 753.3 mm Hg

Table 4E
Davis Vane Anemometer
Serial No. 31125B

Indicated Air Speed, fpm	True Air Speed, fpm
781	731
1056	978
3260	3000
5460	4960
7780	6960
10,310	8970

T = 26.8 ^{o}C
B = 744.6 to 753.0 mm Hg

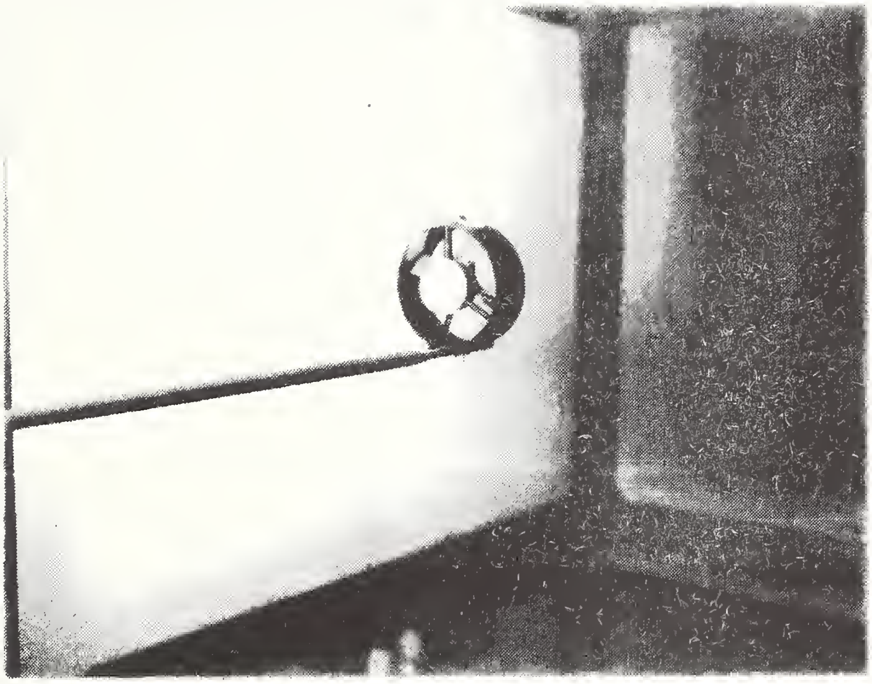

FIGURE 1. THE ANEMOMETER MOUNTED IN THE TUNNEL SHOWING METHOD OF SUPPORT.

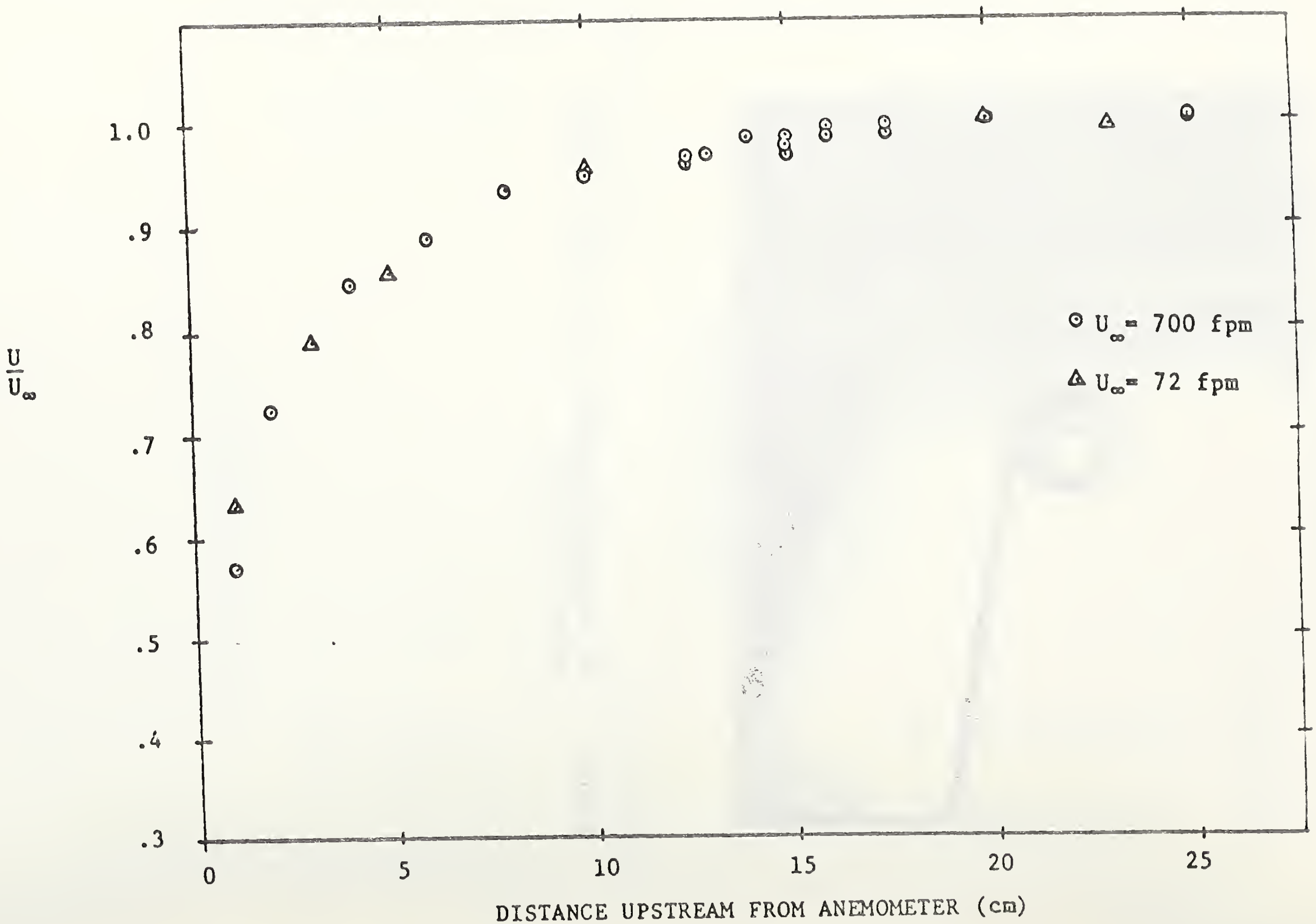

FIGURE 2. VARIATION IN VELOCITY WITH DISTANCE UPSTREAM FROM ANEMOMETER.

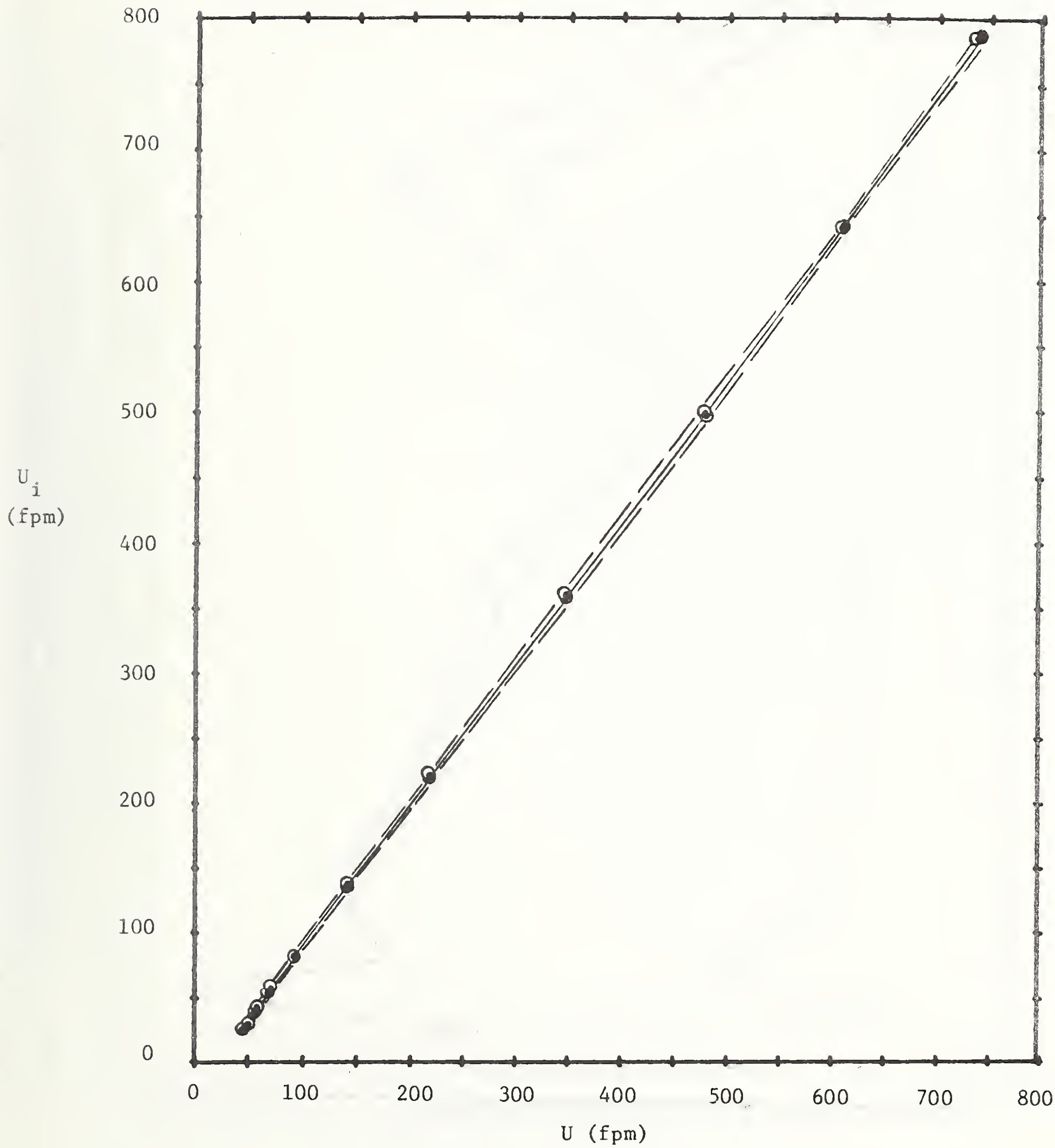

FIGURE 3. INDICATED VERSUS TRUE VELOCITY WITH ± 2σ CURVES.

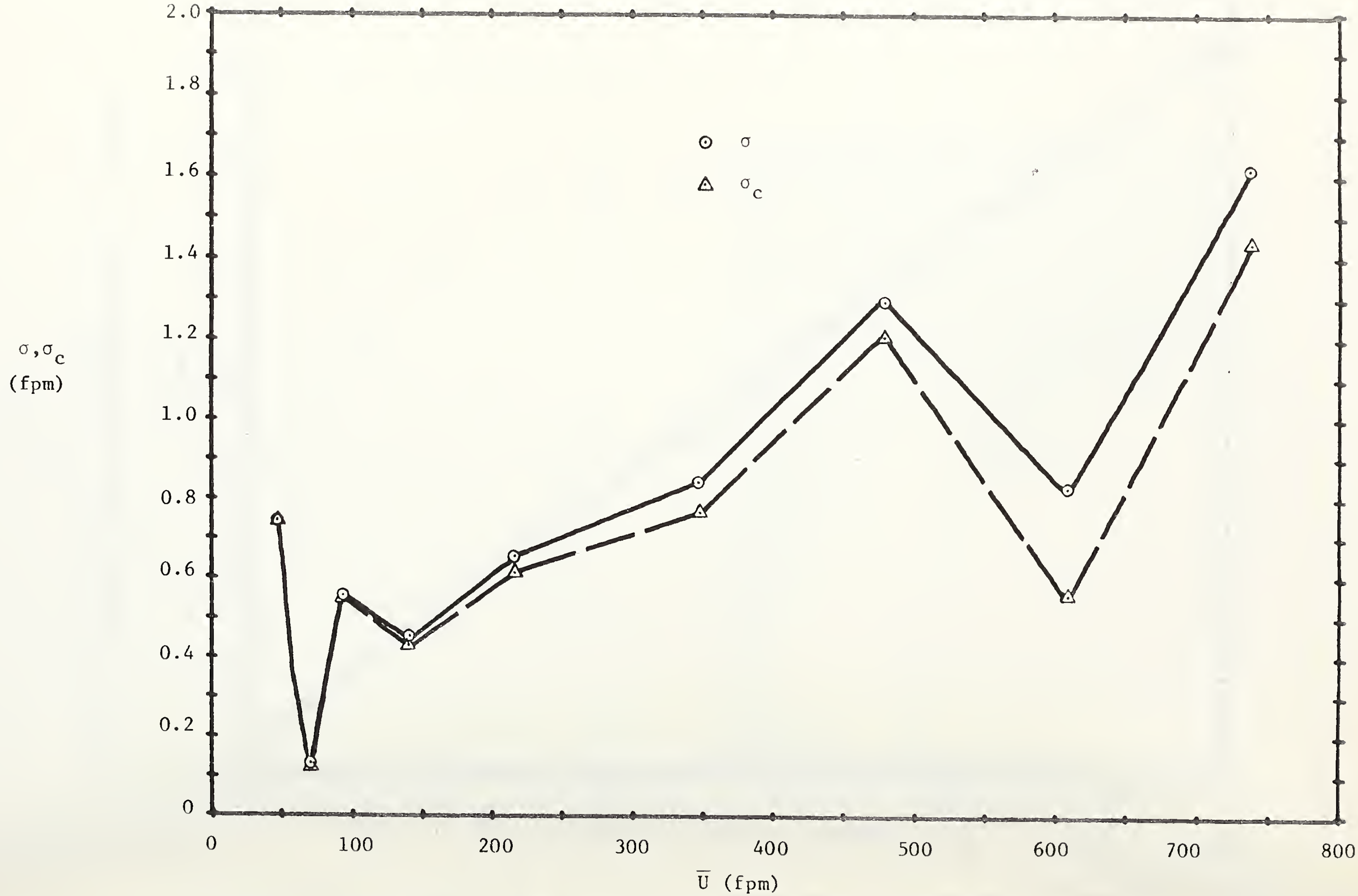

FIGURE 4. STANDARD DEVIATION, σ, AND CORRECTED STANDARD DEVIATION, σ_c, OF INDICATED VELOCITY IN TERMS OF TRUE VELOCITY.

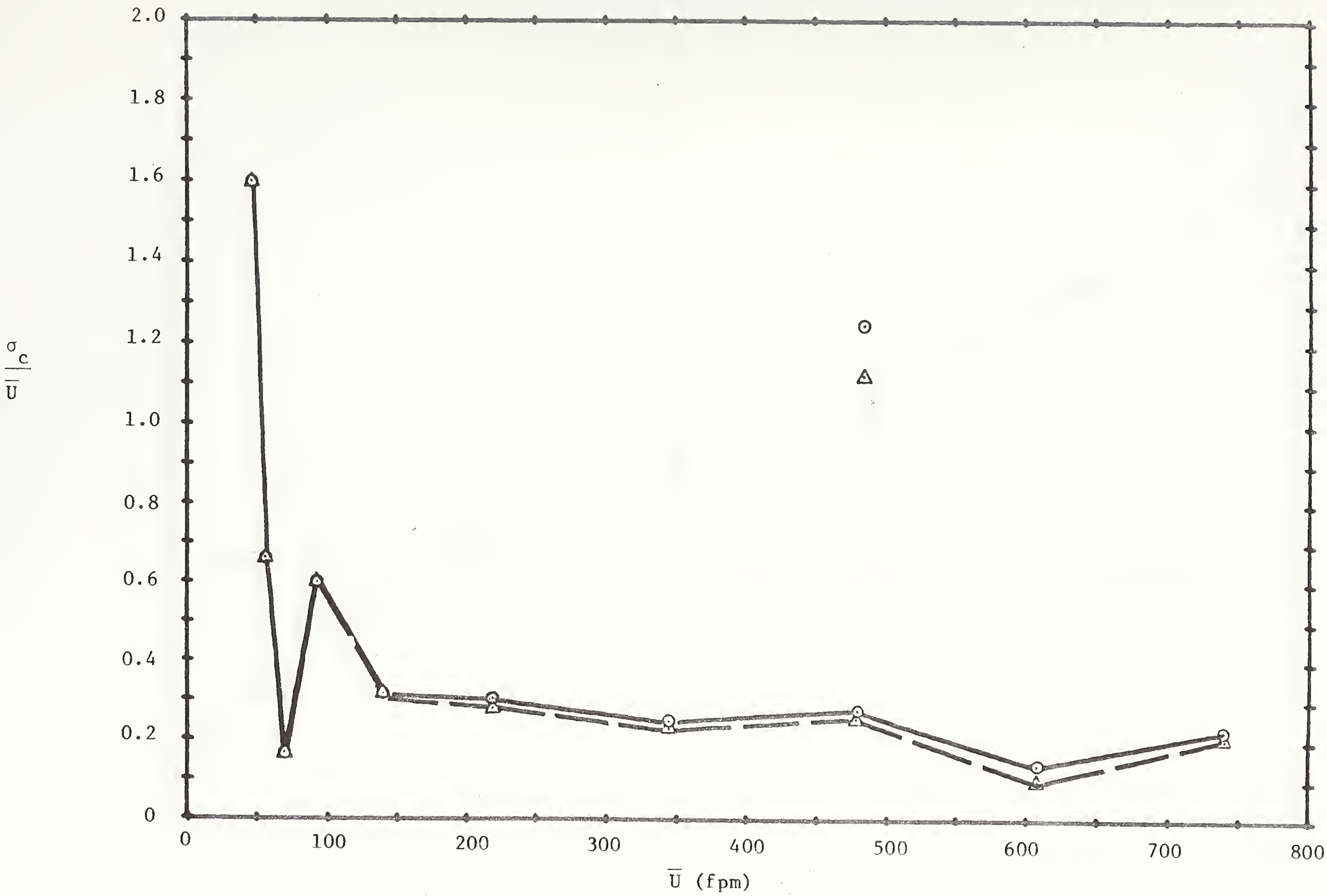

FIGURE 5. STANDARD DEVIATION, σ, AND CORRECTED STANDARD DEVIATION, σ_c, AS PERCENT OF GROUP MEAN VELOCITY.

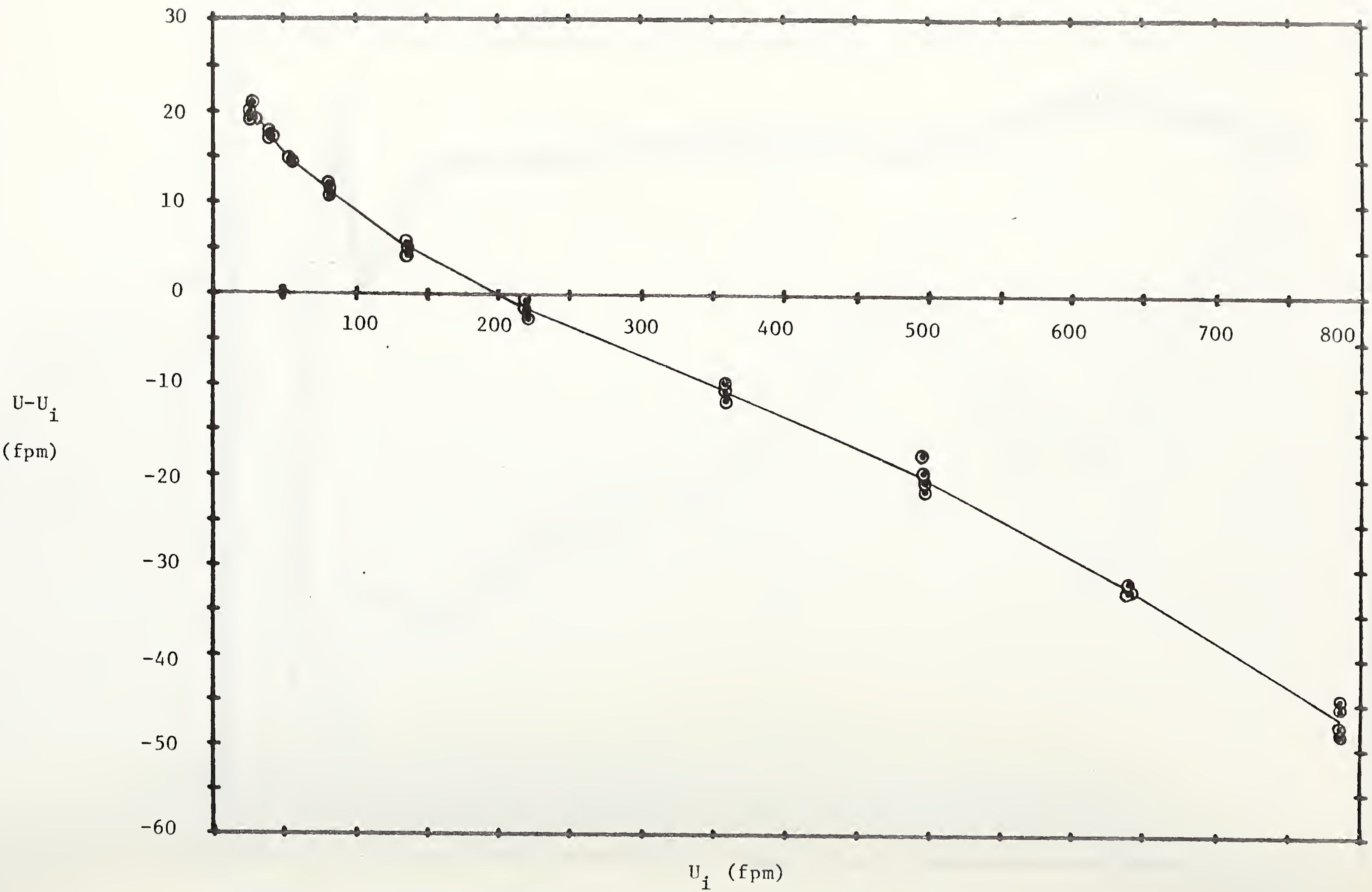

FIGURE 6. DEVIATION OF INDICATED VELOCITY FROM TRUE VELOCITY.

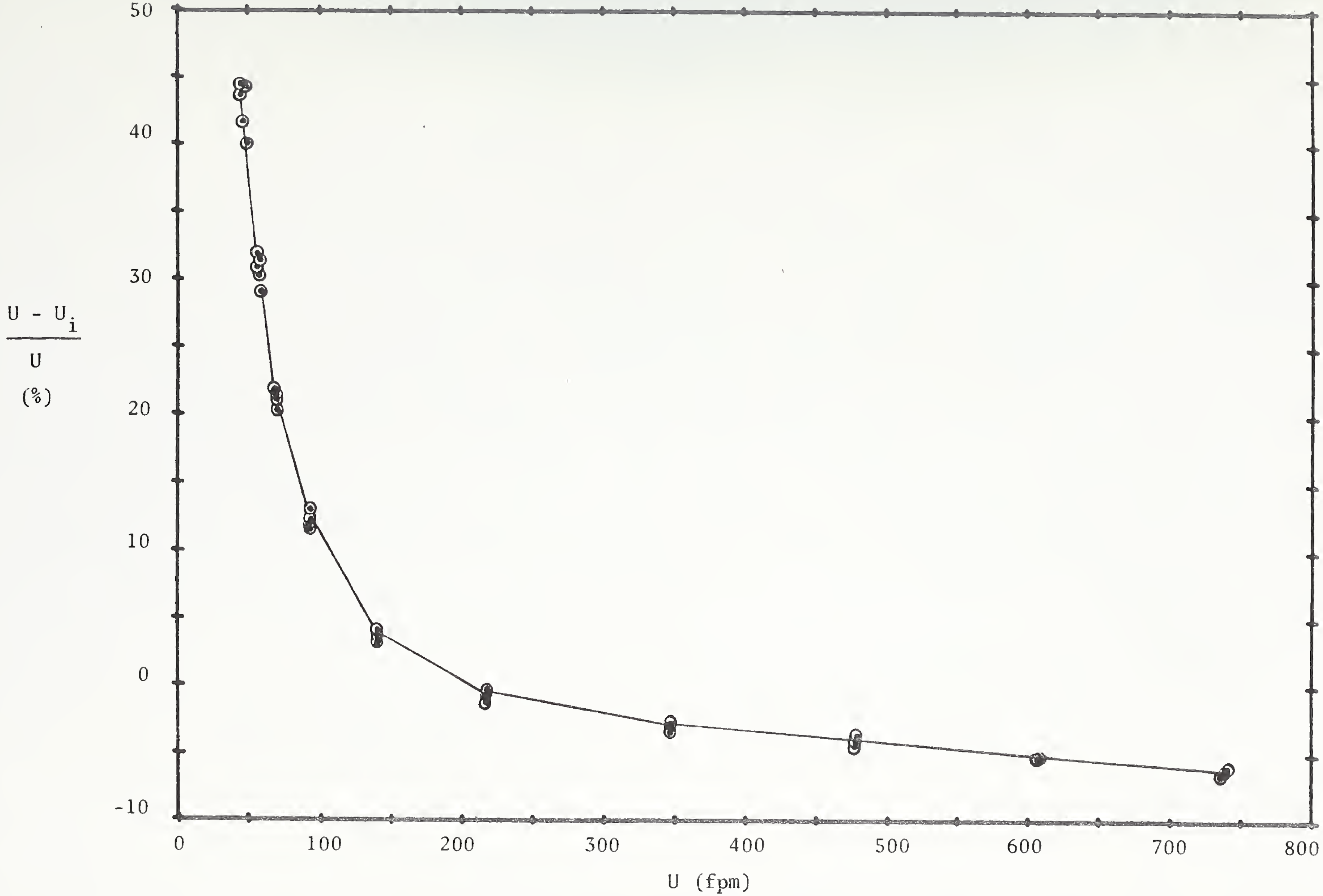

FIGURE 7. PERCENT DEVIATION OF INDICATED VELOCITY FROM TRUE VELOCITY.